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(54) **MEMORY INTERFACE TRAINING**

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G06F 3/06 (2006.01)

(52) **U.S. Cl.**
CPC **G06F 3/0659** (2013.01); **G06F 3/0604** (2013.01); **G06F 3/0673** (2013.01)

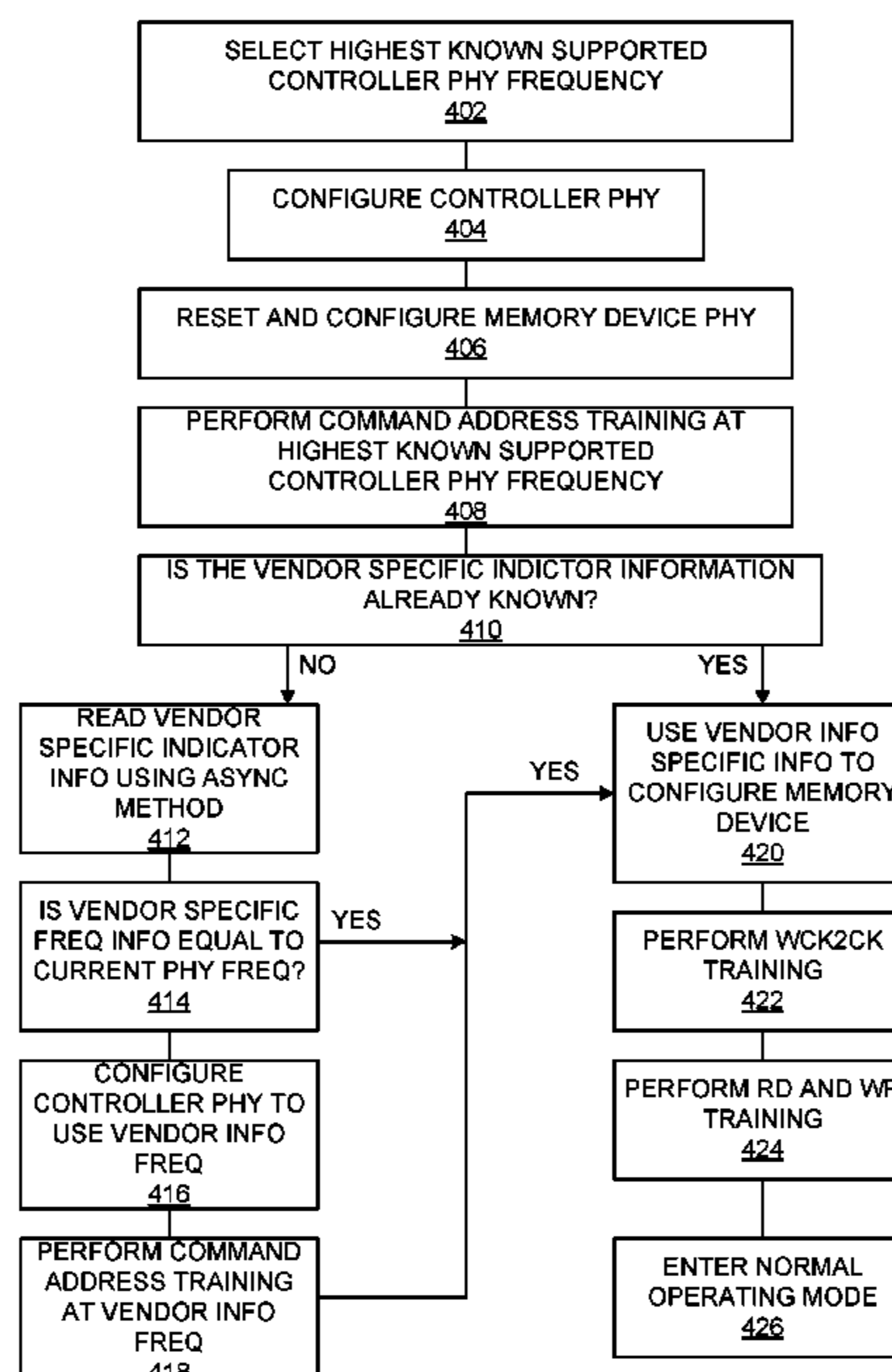
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CPC G06F 3/0659; G06F 3/0604; G06F 3/0673; G06F 13/1689; Y02D 10/00; G11C 29/023; G11C 7/222; G11C 2207/2254; G11C 29/028

See application file for complete search history.

(57) **ABSTRACT**

A command/address (CA) interface of a memory controller coupled to a memory component is trained (e.g., voltages and timings are adjusted to maximize signal eye opening, sample timing margins etc.) while the CA interface is operated at highest known supported controller PHY frequency. After the CA interface has been trained at highest known supported controller PHY frequency, vendor specific information (e.g., vendor ID number, clock configuration, VDDQ configuration, etc.) is read from the memory component. If the vendor specific information indicates that the CA interface may be operated at a different (e.g., higher) frequency, the memory controller reconfigures its physical interface to operate at the indicated frequency. The memory controller then re-trains its CA interface while operating the CA interface at the indicated frequency.

9 Claims, 8 Drawing Sheets



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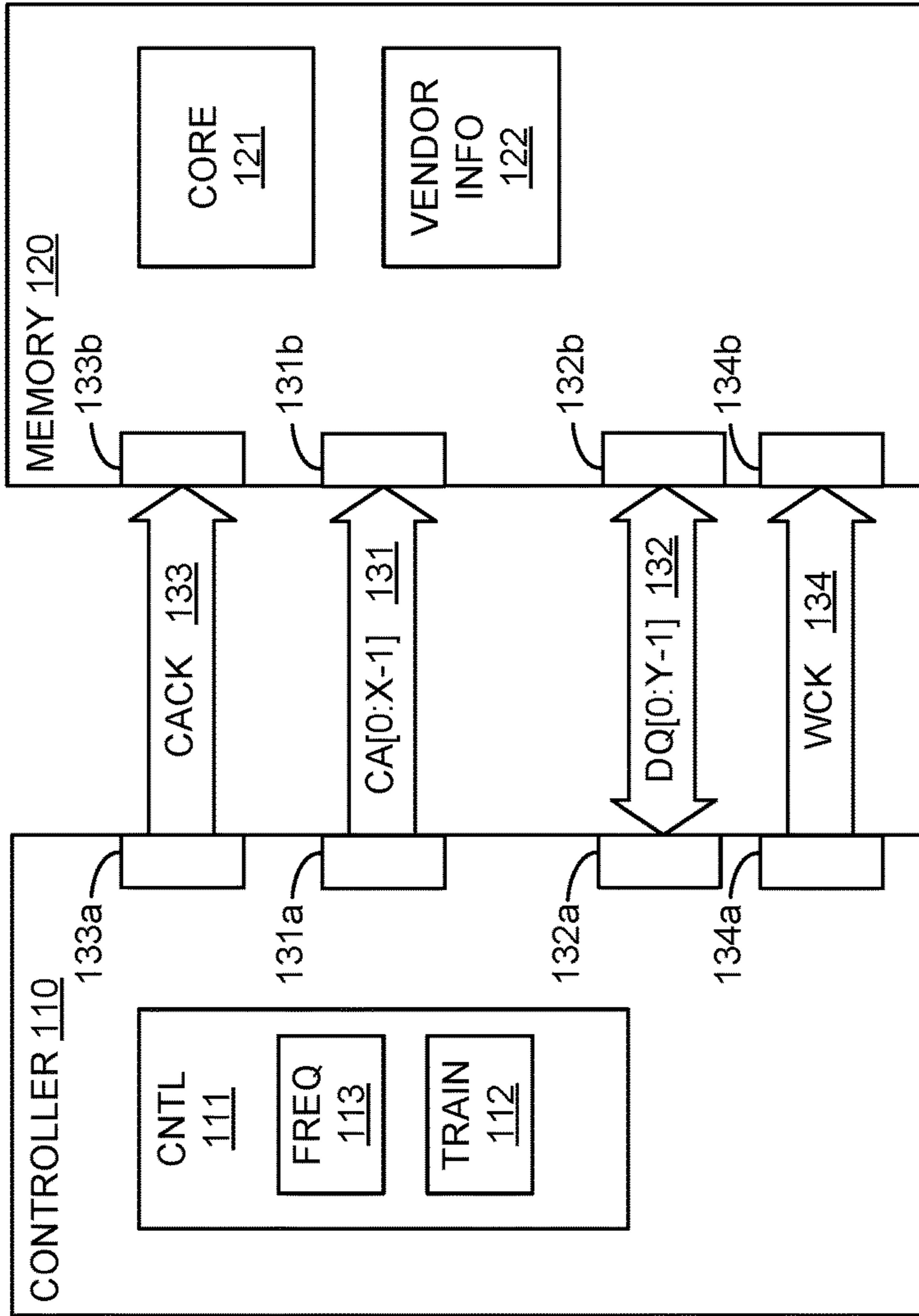


FIG. 1A

100 →

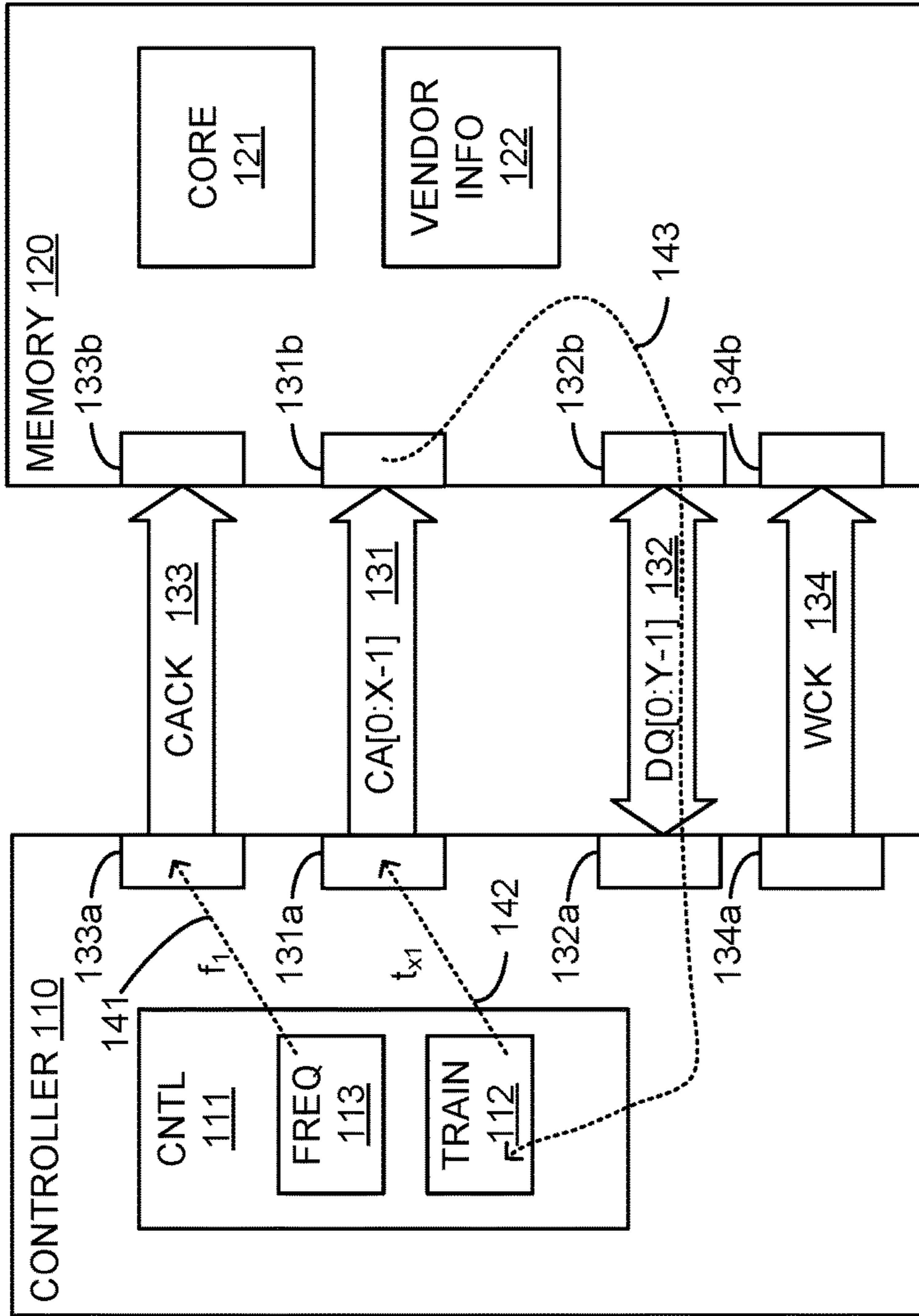


FIG. 1B

100 →

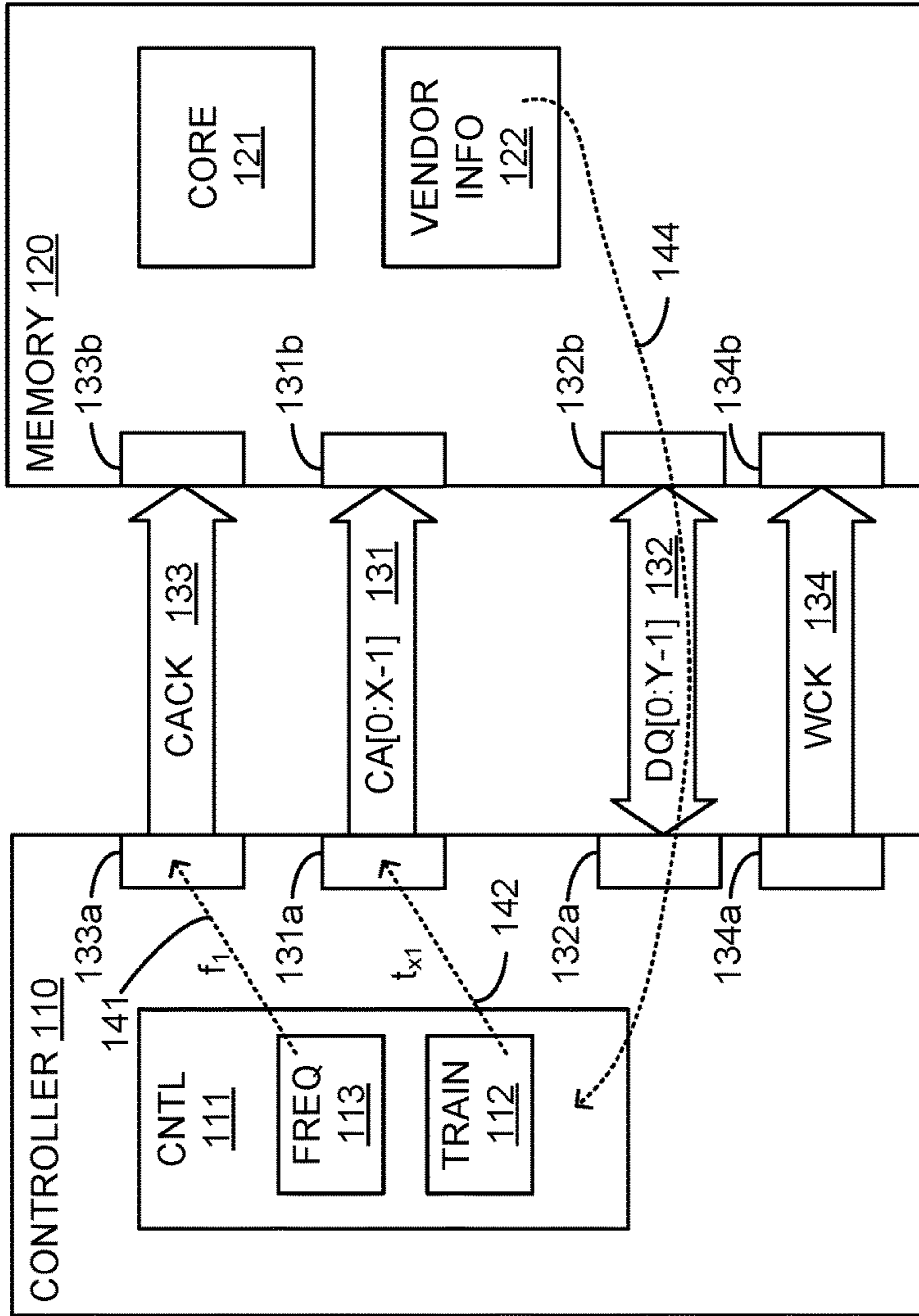


FIG. 1C

100 →

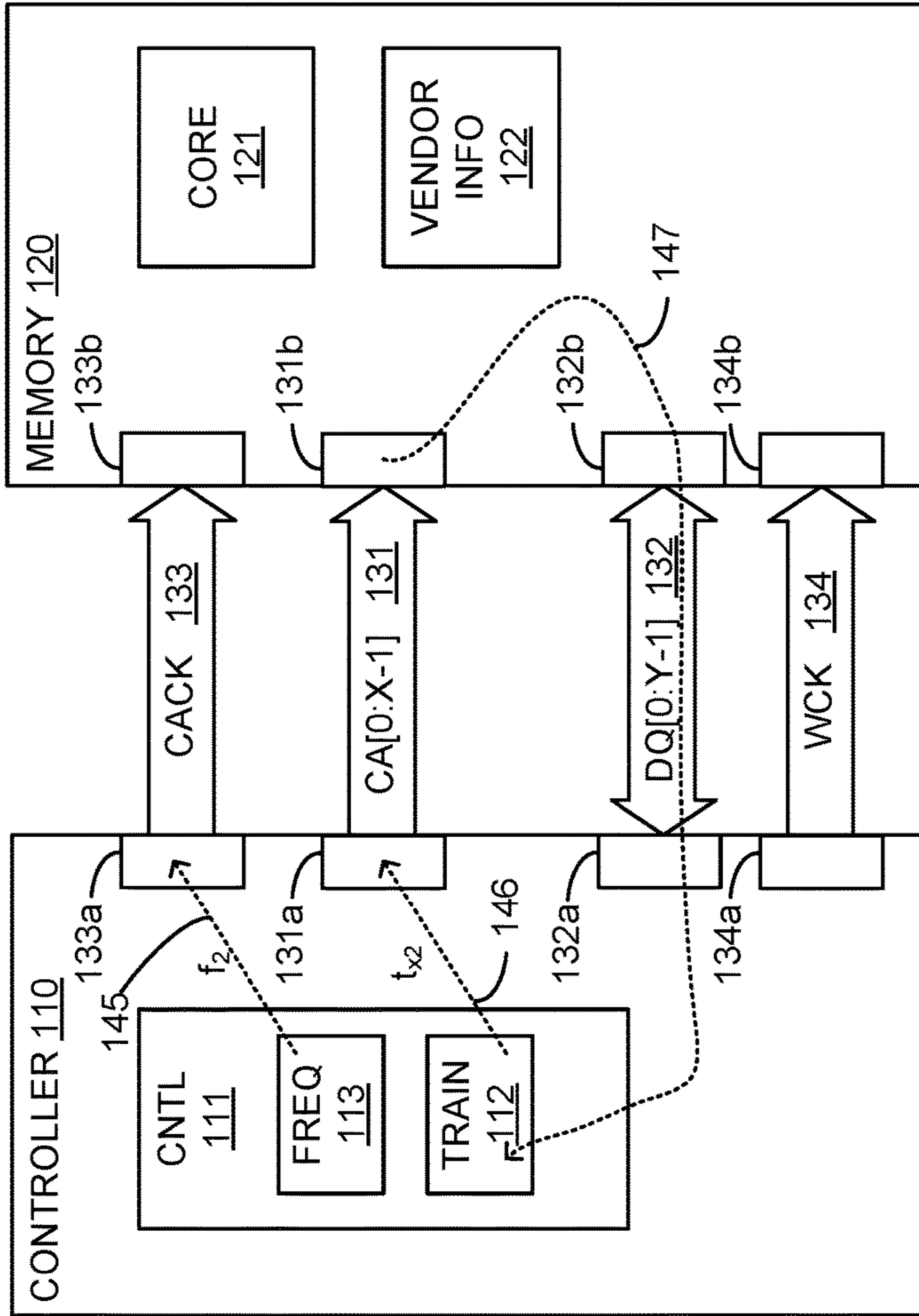
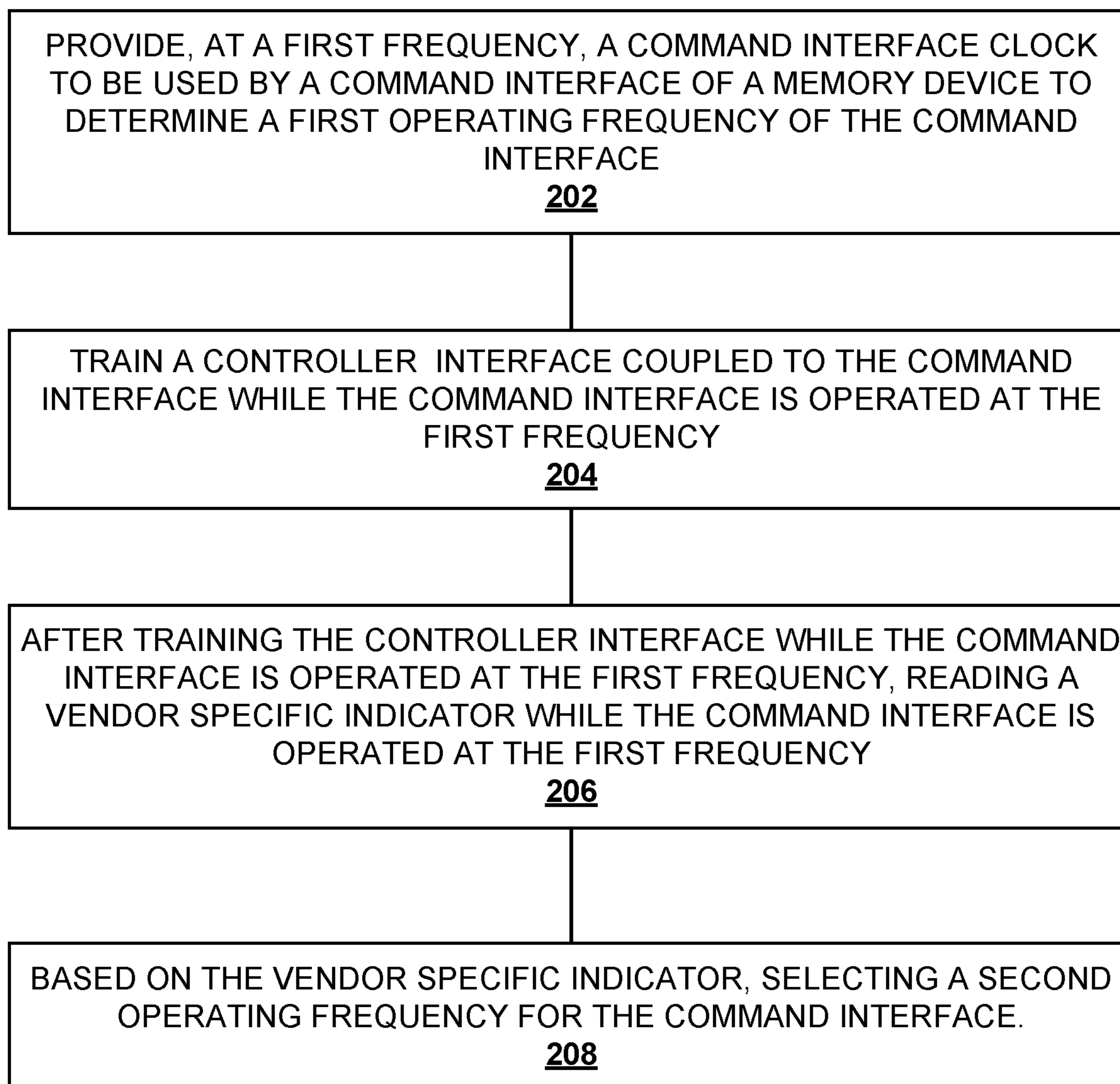
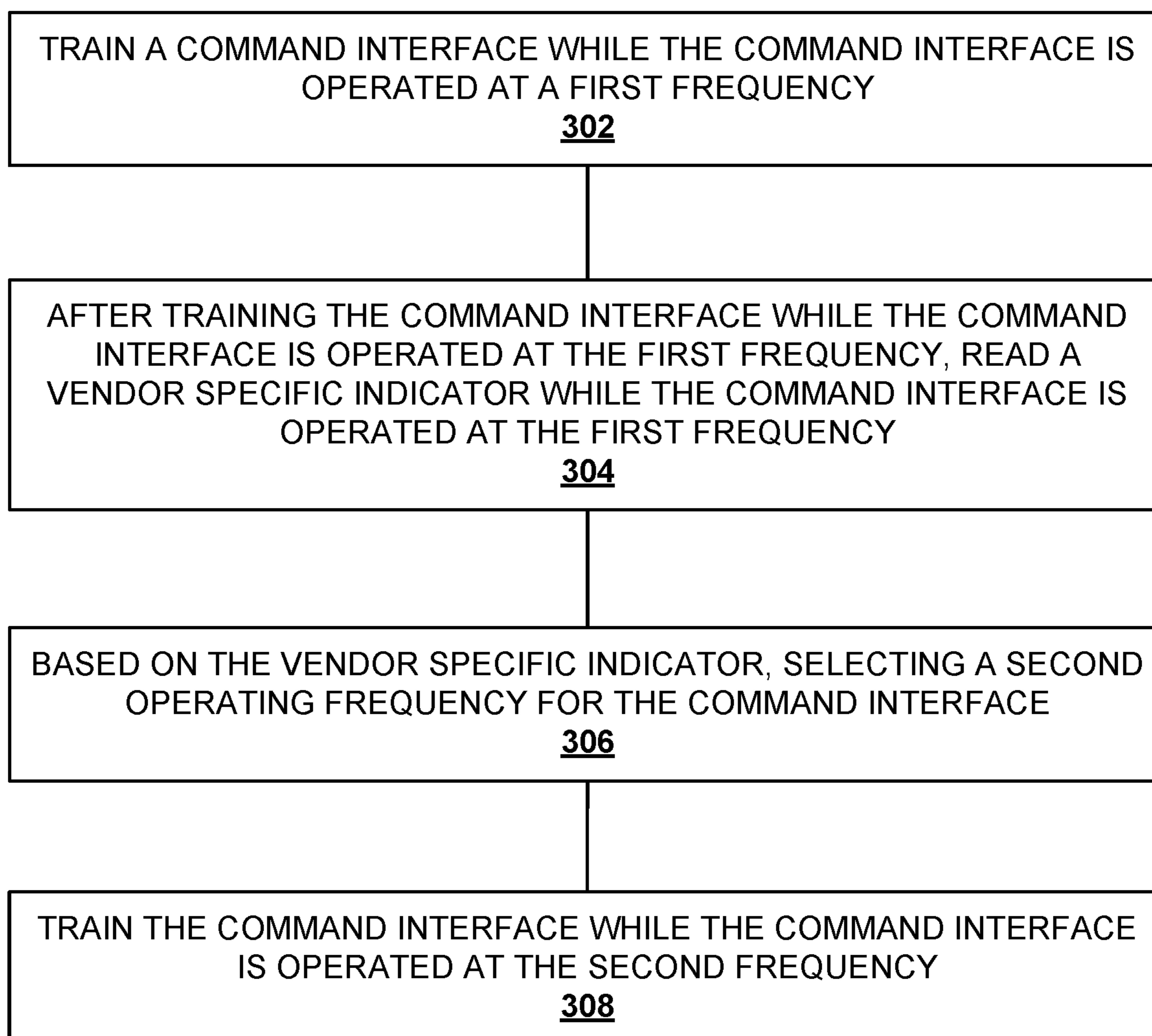


FIG. 1D

**FIG. 2**

**FIG. 3**

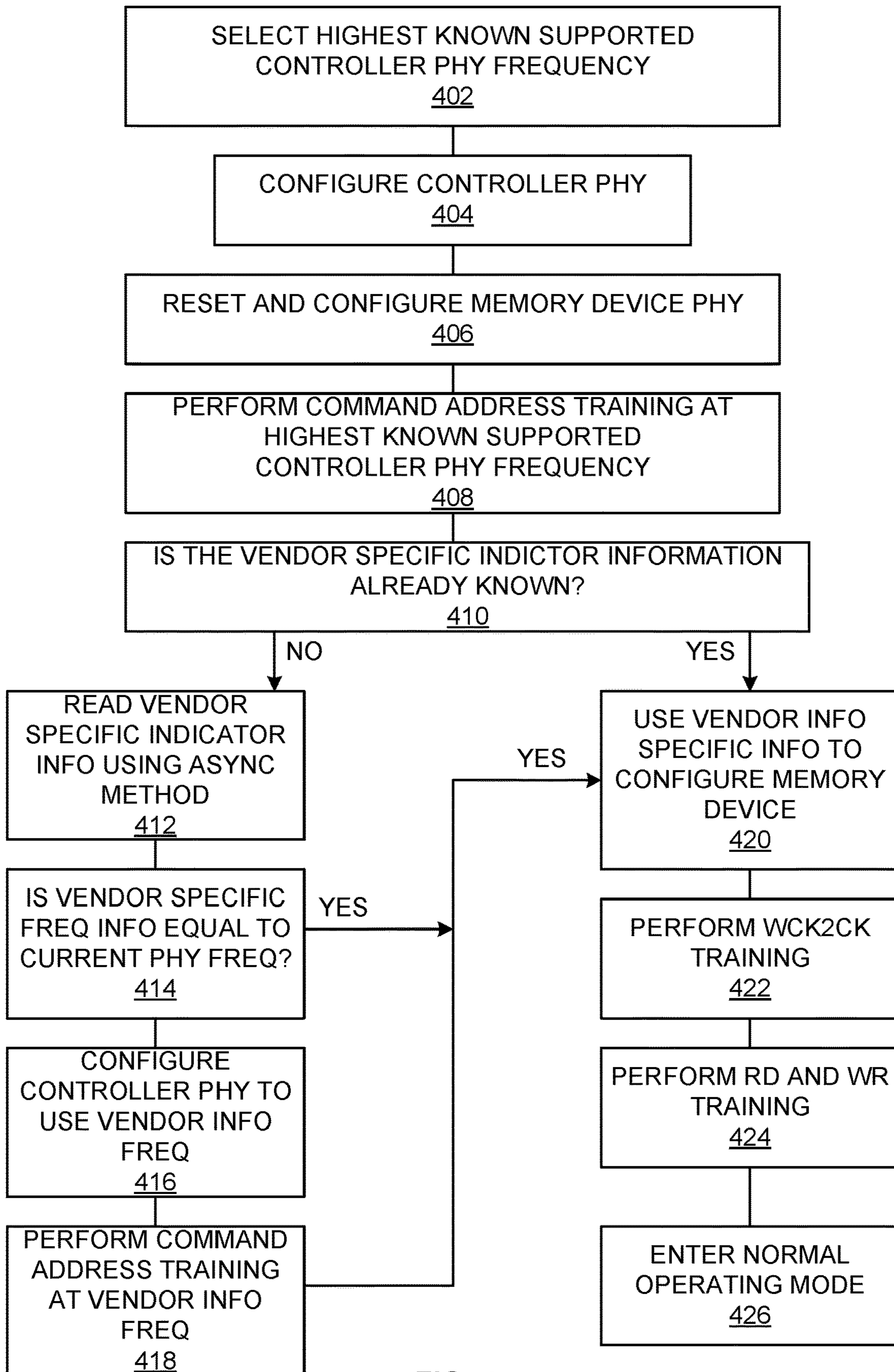


FIG. 4

500 →

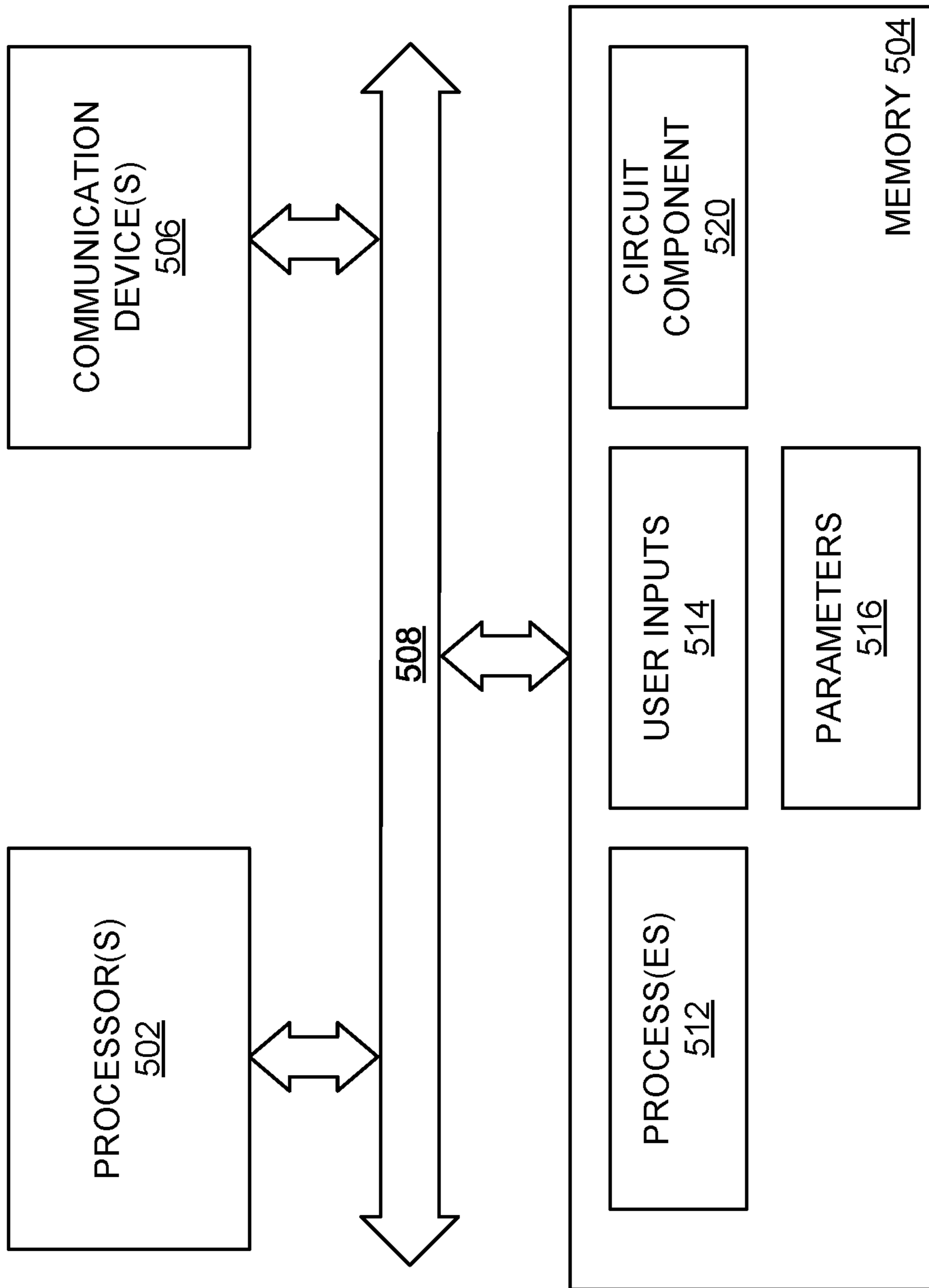


FIG. 5

MEMORY INTERFACE TRAINING

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1A-1D are diagrams illustrating a memory system. 5
 FIG. 2 is a flowchart of a method of operating a memory system.
 FIG. 3 is a flowchart illustrating a method of re-training a memory system.
 FIG. 4 is a flowchart illustrating a method of configuring a memory component interface. 10
 FIG. 5 is a block diagram of a processing system.

DETAILED DESCRIPTION OF THE EMBODIMENTS

A memory controller (a.k.a., a controller) or memory controller design may be used with different memory component designs (e.g., devices from different vendors) that may have different configurations, features, operating frequencies, etc. In an embodiment, during initialization of a memory system, a memory controller configures its physical interface (PHY) to operate a highest known supported frequency. This highest known supported frequency is one which is known to be supported by the memory components and controller without knowing vendor identification details. The command/address (CA) interface of the memory controller is trained (e.g., voltages and timings are adjusted to maximize signal eye opening, sample timing margins etc.) while the CA interface is operated at this highest known supported frequency. 20

In an embodiment, after the CA interface has been trained at the highest known supported frequency, vendor specific information (e.g., vendor ID number, clock configuration, VDDQ configuration, etc.) is read from the memory component. If the vendor specific information indicates that the CA interface may be operated at a different (e.g., higher) frequency, the memory controller reconfigures its physical interface to operate at the indicated frequency. The memory controller then re-trains its CA interface while operating the CA interface at the indicated frequency. Thus, when the re-training is complete, the CA interface is ready (and trained) to operate at the frequency indicated by the vendor specific information. 25

FIGS. 1A-1D are diagrams illustrating a memory system. In FIGS. 1A-1D, memory system 100 comprises controller 110 and memory component 120. Controller 110 includes control circuitry 111, command/address (CA) interface 131a, data (DQ) interface 132a, CA clock (CACK) interface 133a, and data clock interface 134a. Control circuitry 111 includes frequency control circuitry 113 and training control circuitry 112. Memory component 120 includes memory core 121 (a.k.a., storage cell array), vendor specific information 122, CA interface 131b, DQ interface 132b, CA clock (CACK) interface 133b, and data clock interface 134b. 30

Controller 110 and memory component 120 may be integrated circuit type devices, such as are commonly referred to as a “chips”. A memory controller, such as controller 120, manages the flow of data going to and from memory devices and/or memory modules. Memory component 120 (also referred to as memory component 120) may be a standalone device, or may be a component of a memory module. Memory component 120 may be a device that adheres to, or is compatible with, a Graphics Double Data Rate 6 (GDDR6) Synchronous Graphics Random Access Memory (SGRAM) specification. A memory controller can be a separate, standalone chip, or integrated into another 35

chip. For example, a memory controller may be included on a single die with a microprocessor, or included as part of a more complex integrated circuit system such as a block of a system on a chip (SOC).

Controller 110 is operatively coupled to memory component 120 via CA interface 131a that is coupled to CA signal lines 131. CA signal lines 131 (and corresponding CA interface 131a on controller 110 and CA interface 131b on memory component 120) may be composed of X number of signal lines. In an embodiment, X=9. In an embodiment, CA signal lines 131 may include one or more (e.g., 1) data bus inversion (DBI) signal lines. Controller 110 is operatively coupled to memory component 120 to send commands and associated information (e.g., addresses) to memory component 120 via CA signal lines 131. Memory component 120 receives these commands (and associated information—e.g., addresses) via CA interface 131b that is also coupled to CA signal lines 131. 40

Controller 110 is also operatively coupled to memory component 120 via command/address clock (CACK) interface 133a that is coupled to CACK signal lines 133. CACK signal lines 133 (and corresponding CACK interface 133a on controller 110 and CACK interface 133b on memory component 120) may be composed of a plurality of number of differential signal lines. In an embodiment, there are two (2) CACK clock signal lines that carry a differential clock signal. Controller 110 is operatively coupled to memory component 120 to send a timing reference signal to memory component 120 via CACK signal lines 133. Memory component 120 receives the timing reference signal via CACK interface 133b that is also coupled to CACK signal lines 133. Memory component 120 uses the timing reference signal to determine the sample timing and frequency of operation of CA interface 131b. In an embodiment not illustrated in FIG. 1, controller 110 and memory component 120 may be coupled via multiple CA interfaces (e.g., 2 or Y=36) that share CACK signal lines 133. 45

Controller 110 is operatively coupled to memory component 120 via DQ interface 132a that is coupled to DQ signal lines 132. DQ signal lines 132 (and corresponding DQ interface 132a on controller 110 and DQ interface 132b on memory component 120) may be composed of Y number of signal lines. In an embodiment, Y=18. In an embodiment, DQ signal lines 132 may include one or more (e.g., 2) DBI signal lines. Controller 110 and memory component 120 are operatively coupled via DQ signal lines 132 to bidirectionally communicate data. Memory component 120 may store (e.g., in memory core 121) and retrieve (e.g., from memory core 121) data communicated via DQ interface 132b and DQ signal lines 132. 50

Controller 110 is also operatively coupled to memory component 120 via data clock (WCK) interface 134a that is coupled to WCK signal lines 134. WCK signal lines 134 (and corresponding WCK interface 134a on controller 110 and WCK interface 134b on memory component 120) may be composed of a plurality of number of differential signal lines. In an embodiment, there are two (2) WCK clock signal lines that carry a differential clock signal. Controller 110 is operatively coupled to memory component 120 to send a timing reference signal to memory component 120 via WCK signal lines 134. Memory component 120 receives the timing reference signal via WCK interface 134b that is also coupled to WCK signal lines 134. Memory component 120 uses the timing reference signal to determine the sample timing, transmit timing, and frequency of operation of DQ interface 132b (and by extension DQ interface 132a). 55

In an embodiment, after being reset, memory component **120** is initialized by controller **110**. As part of the initialization process, controller **110** provides, from CACK interface **133a** and at a first frequency (f_1), a command/address clock signal to be used by memory component **120** to determine a first operating frequency of CA interface **131b**. This is illustrated in FIG. 1B by arrow **141** running from frequency control circuitry **113** to CACK interface **133a**.

Also, as part of the initialization process, controller **110** trains CA interface **131a** while CA interface **131a** and CA interface **131b** are operated at the first frequency. To receive the results and intermediate results of training adjustments to CA interface **131a** and/or CACK interface **133a**, controller **110** may place memory component **120** into a training mode.

Controller **110** may place memory component **120** into a training mode by, for example, issuing a mode register set (MRS) command to memory component **120** via CA interface **131a**, CA signal lines **131**, and CA interface **131b**. The training mode that memory component **120** is placed into may cause bridging of the values received at CA interface **131b** to DQ interface **132b**. One or more values received at CA interface **131b** may be transmitted to controller **110** via DQ interface **132b**, DQ signal lines **132**, and DQ interface **132b**. Controller **110** may then compare the patterns received by memory component **120** to expected values and adjust CA interface **131a** transmit timings (t_{x1}) accordingly. This procedure may be repeated using different patterns and CA interface **131a** interface timings. This is illustrated in FIG. 1B by arrow **142** running from training control circuitry **112** to CA interface **131a** and arrow **143** running from CA interface **131b** of memory component **120** to training control circuitry **112** via DQ interface **132b**, DQ signal lines **132**, and DQ interface **132a**.

Controller **110** may place memory component **120** into a training mode by, for example, issuing a mode register set (MRS) command to memory component **120** via CA interface **131a**, CA signal lines **131**, and CA interface **131b**. The training mode that memory component **120** is placed into may cause bridging of the values received at CA interface **131b** to DQ interface **132b**. One or more values received at CA interface **131b** may be transmitted to controller **110** via DQ interface **132b**, DQ signal lines **132**, and DQ interface **132a**. Controller **110** may then compare the patterns received by memory component **120** to expected values and adjust CA interface **131a** transmit timings (t_{x1}) accordingly. This procedure may be repeated using different patterns and CA interface **131a** interface timings. This is illustrated in FIG. 1B by arrow **142** running from training control circuitry **112** to CA interface **131a** and arrow **143** running from CA interface **131b** of memory component **120** to training control circuitry **112** via DQ interface **132b**, DQ signal lines **132**, and DQ interface **132a**.

In an embodiment, based on the vendor specific indicator, control circuitry **111** may select a second operating frequency for CA interface **131a**, CA signal lines **131**, and CA interface **131b**. For example, if the vendor specific information **122** indicates that memory component **120** (and CA interface **131b**, in particular) may be operated at a second and different (e.g., higher) frequency than it is currently being operated, control circuitry **111** may (via frequency control circuitry **113**) configure CACK interface **133a** to operate at this second frequency (e.g., f_2).

In an embodiment, while CACK interface **133a** (and thus CA interface **131a**, CA signal lines **131**, and CA interface **131b**) is operating at this second frequency (e.g., f_2), controller **110** may retrain CA interface **131a**. Thus, based on the vendor specific indicator received from memory com-

ponent **120**, CA interface **131a** may be retrained while operating at the second frequency resulting in retrained transmit timings (t_{x2}). This is illustrated in FIG. 1D by arrow **145** running from frequency control circuitry **113** to CACK interface **133a**, arrow **146** running from training control circuitry **112** to CA interface **131a**, and arrow **147** running from CA interface **131b** of memory component **120** to training control circuitry **112** via DQ interface **132b**, DQ signal lines **132**, and DQ interface **132a**.

FIG. 2 is a flowchart of a method of operating a memory system. One or more steps illustrated in FIG. 2 may be performed by, for example, memory system **100**, and/or its components. At a first frequency, a command interface clock is provided to be used by a command interface of a memory device to determine a first operating frequency of the command interface (**202**). For example, controller **110** may provide, via CACK interface **133a**, CACK signal lines **133** and CACK interface **133b** and to memory component **120**, a CACK clock signal that is cycling at a first frequency (e.g., f_1).

A controller interface coupled to the command interface is trained while the command interface is operated at the first frequency (**204**). For example, Controller **110** may place memory component **120** into a training mode by issuing an MRS command to memory component **120** via CA interface **131a**, CA signal lines **131**, and CA interface **131b**. The training mode causes the bridging of the values received at CA interface **131b** to DQ interface **132b** where these values are transmitted to controller **110** via DQ interface **132b**, DQ signal lines **132**, and DQ interface **132b**. Controller **110** then compares the patterns received by memory component **120** to expected values and adjusts CA interface **131a** transmit timings (t_{x1}) accordingly. This procedure may be repeated using different patterns and CA interface **131a** interface timings.

A controller interface coupled to the command interface is trained while the command interface is operated at the first frequency (**204**). For example, Controller **110** may place memory component **120** into a training mode by issuing an MRS command to memory component **120** via CA interface **131a**, CA signal lines **131**, and CA interface **131b**. The training mode causes the bridging of the values received at CA interface **131b** to DQ interface **132b** where these values are transmitted to controller **110** via DQ interface **132b**, DQ signal lines **132**, and DQ interface **132a**. Controller **110** then compares the patterns received by memory component **120** to expected values and adjusts CA interface **131a** transmit timings (t_{x1}) accordingly. This procedure may be repeated using different patterns and CA interface **131a** interface timings.

Based on the vendor specific indicator, a second operating frequency for the command interface is selected (**208**). For example, controller **110** may, based on the vendor specific indicator, select a second operating frequency for CA interface **131a**. Thus, for example, if the vendor specific information **122** indicates that memory component **120** (and CA interface **131b**, in particular) may be operated at a higher frequency than it is currently being operated, control circuitry **111** may (via frequency control circuitry **113**) configure CACK interface **133a** to select a second frequency (e.g., f_2) for the CACK clock signal to be cycled at.

FIG. 3 is a flowchart illustrating a method of re-training a memory system. One or more steps illustrated in FIG. 3 may be performed by, for example, memory system **100**, and/or its components. A command interface is trained while the command interface is operated at a first frequency (**302**). For example, while CACK interface **133a** is transmitting a

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clock signal having a first frequency, controller 110 may transmit test pattern values to memory component 120 via CA interface 1321a. Memory component 120 may transmit the values received at CA interface 131b back to controller 110. Controller 110 may then compare the test pattern values received by memory component 120 to the transmitted test pattern values. Based on these comparisons, controller 110 (and training control circuitry 112, in particular) may adjust one or more transmit timings used by CA interface 131a.

FIG. 3 is a flowchart illustrating a method of re-training a memory system. One or more steps illustrated in FIG. 3 may be performed by, for example, memory system 100, and/or its components. A command interface is trained while the command interface is operated at a first frequency (302). For example, while CACK interface 133a is transmitting a clock signal having a first frequency, controller 110 may transmit test pattern values to memory component 120 via CA interface 131a. Memory component 120 may transmit the values received at CA interface 131b back to controller 110. Controller 110 may then compare the test pattern values received by memory component 120 to the transmitted test pattern values. Based on these comparisons, controller 110 (and training control circuitry 112, in particular) may adjust one or more transmit timings used by CA interface 131a.

Based on the vendor specific indicator, a second operating frequency for the command interface is selected (306). For example, the vendor specific information 122 may indicate that memory component 120 (and CA interface 131b, in particular) can be operated at a higher frequency. In response, controller 110 may cause CACK interface 133a to output a clock signal at the higher frequency.

The command interface is trained while the command interface is operated at the second frequency (308). For example, while CACK interface 133a is transmitting a clock signal having the second frequency, controller 110 may transmit test pattern values to memory component 120 via CA interface 1321a. Memory component 120 may transmit the values received at CA interface 131b back to controller 110. Controller 110 may then compare the test pattern values received by memory component 120 to the transmitted test pattern values. Based on these comparisons, controller 110 (and training control circuitry 112, in particular) may adjust one or more transmit timings used by CA interface 131a.

FIG. 4 is a flowchart illustrating a method of configuring a memory component interface. One or more steps illustrated in FIG. 4 may be performed by, for example, memory system 100, and/or its components. The highest known supported controller PHY frequency is selected (402). For example, the highest known supported frequency for CA interface 131a that is supported by controller 110 and memory component 120 may be selected and used to operate CACK interface 133a and CA interface 131a. This highest known supported frequency is one which is supported by memory component 120 and controller 110 without knowing vendor identification details.

The controller PHY is configured (404). For example, registers in control circuitry 111 may be programmed to define the memory system 100 attributes that are not vendor specific. Examples of configurations include, but are not limited to: whether CA interface 131a and CACK interface 133a are to be on-die terminated; whether memory component 120 is to be operated in x8 (clamshell) mode or x16; whether memory component 120 is to be operated in pseudo mode or 2-channel mode.

The memory device PHY is reset and configured (406). For example, controller 110 may reset and configure memory component 120 with attributes that are not vendor

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specific. Examples of configurations include, but are not limited to: whether CA interface 131b and CACK interface 133b are to be on-die terminated; whether memory component 120 is to be operated in x8 (clamshell) mode or x16; whether memory component 120 is to be operated in pseudo mode or 2-channel mode.

Command address training is performed at the highest known supported controller PHY frequency (408). For example, while CACK interface 133a is transmitting a clock signal at the highest known frequency supported by controller 110 and memory component 120, controller 110 may transmit test pattern values to memory component 120 via CA interface 131a. Memory component 120 may transmit the values received at CA interface 131b back to controller 110. Controller 110 may then compare the test pattern values received by memory component 120 to the transmitted test pattern values. Based on these comparisons, controller 110 (and training control circuitry 112, in particular) may adjust one or more transmit timings used by CA interface 131a.

If the vendor specific indicator information is already known, flow proceeds to box 420. If the vendor specific indicator information is not already known, flow proceeds to box 412 (410). In box 412, the vendor specific indicator information is read using an asynchronous or low speed method (412). For example, controller 110 may read vendor specific information 122 from memory component 120 using an MRS command that statically places the vendor specific indicator information on DQ interface 132b.

If the vendor specific indicator information indicates that CA interface 131b may be operated at a higher frequency than the highest known supported controller PHY frequency, flow proceeds to box 416. If the vendor specific indicator information indicates that the highest frequency CA interface 131b may be operated at is highest known supported controller PHY frequency, flow proceeds to box 420 (414). In box 416, the controller PHY is configured to use the frequency specified by the vendor specific indicator information (416). For example, controller 110 may cause CACK interface 133a to output a clock signal at the frequency specified by the vendor specific indicator information.

Command address training is performed at the vendor specific indicator information frequency (418). For example, while CACK interface 133a is transmitting a clock signal having a frequency specified by the vendor specific indicator information, controller 110 may transmit test pattern values to memory component 120 via CA interface 131a. Memory component 120 may transmit the values received at CA interface 131b back to controller 110. Controller 110 may then compare the test pattern values received by memory component 120 to the transmitted test pattern values. Based on these comparisons, controller 110 (and training control circuitry 112, in particular) may adjust one or more transmit timings used by CA interface 131a.

Vendor specific indicator information is used to configure the memory device (420). For example, controller 110 may transmit MRS commands to memory component 120 that set one or more of: (1) latency; (2) vendor specific features; (3) DQ termination; (4) WCK termination; (5) DQ drive strength; (6) WCK drive strength, etc. WCK2CK training is performed (422). For example, controller 110 may adjust a phase relationship between the timing reference signal transmitted from CACK interface 133a and the timing reference signal transmitted from data clock interface 134a.

Read and write training are performed (424). For example, controller 110 may adjust a phase relationship between the timing reference signal transmitted from data

clock interface **134a** and values transferred via DQ interface **132a** and DQ interface **132b**. Normal operating mode is entered (**426**).

The methods, systems and devices described above may be implemented in computer systems, or stored by computer systems. The methods described above may also be stored on a non-transitory computer readable medium. Devices, circuits, and systems described herein may be implemented using computer-aided design tools available in the art, and embodied by computer-readable files containing software descriptions of such circuits. This includes, but is not limited to one or more elements of memory system **100**, and its components. These software descriptions may be: behavioral, register transfer, logic component, transistor, and layout geometry-level descriptions. Moreover, the software descriptions may be stored on storage media or communicated by carrier waves.

Data formats in which such descriptions may be implemented include, but are not limited to: formats supporting behavioral languages like C, formats supporting register transfer level (RTL) languages like Verilog and VHDL, formats supporting geometry description languages (such as GDSII, GDSIII, GDSIV, CIF, and MEBES), and other suitable formats and languages. Moreover, data transfers of such files on machine-readable media may be done electronically over the diverse media on the Internet or, for example, via email. Note that physical files may be implemented on machine-readable media such as: 4 mm magnetic tape, 8 mm magnetic tape, 3½ inch floppy media, CDs, DVDs, and so on.

FIG. **5** is a block diagram illustrating one embodiment of a processing system **500** for including, processing, or generating, a representation of a circuit component **520**. Processing system **500** includes one or more processors **502**, a memory **504**, and one or more communications devices **506**. Processors **502**, memory **504**, and communications devices **506** communicate using any suitable type, number, and/or configuration of wired and/or wireless connections **508**.

Processors **502** execute instructions of one or more processes **512** stored in a memory **504** to process and/or generate circuit component **520** responsive to user inputs **514** and parameters **516**. Processes **512** may be any suitable electronic design automation (EDA) tool or portion thereof used to design, simulate, analyze, and/or verify electronic circuitry and/or generate photomasks for electronic circuitry. Representation **520** includes data that describes all or portions of memory system **100**, and its components, as shown in the Figures.

Representation **520** may include one or more of behavioral, register transfer, logic component, transistor, and layout geometry-level descriptions. Moreover, representation **520** may be stored on storage media or communicated by carrier waves.

Data formats in which representation **520** may be implemented include, but are not limited to: formats supporting behavioral languages like C, formats supporting register transfer level (RTL) languages like Verilog and VHDL, formats supporting geometry description languages (such as GDSII, GDSIII, GDSIV, CIF, and MEBES), and other suitable formats and languages. Moreover, data transfers of such files on machine-readable media may be done electronically over the diverse media on the Internet or, for example, via email

User inputs **514** may comprise input parameters from a keyboard, mouse, voice recognition interface, microphone and speakers, graphical display, touch screen, or other type of user interface device. This user interface may be distrib-

uted among multiple interface devices. Parameters **516** may include specifications and/or characteristics that are input to help define representation **520**. For example, parameters **516** may include information that defines device types (e.g., NFET, PFET, etc.), topology (e.g., block diagrams, circuit descriptions, schematics, etc.), and/or device descriptions (e.g., device properties, device dimensions, power supply voltages, simulation temperatures, simulation models, etc.).

Memory **504** includes any suitable type, number, and/or configuration of non-transitory computer-readable storage media that stores processes **512**, user inputs **514**, parameters **516**, and circuit component **520**.

Communications devices **506** include any suitable type, number, and/or configuration of wired and/or wireless devices that transmit information from processing system **500** to another processing or storage system (not shown) and/or receive information from another processing or storage system (not shown). For example, communications devices **506** may transmit circuit component **520** to another system. Communications devices **506** may receive processes **512**, user inputs **514**, parameters **516**, and/or circuit component **520** and cause processes **512**, user inputs **514**, parameters **516**, and/or circuit component **520** to be stored in memory **504**.

Implementations discussed herein include, but are not limited to, the following examples:

Example 1: A method, comprising: providing, at a first frequency, a command interface clock to be used by a command interface of a memory component to determine a first operating frequency of the command interface; training the command interface while the command interface is operated at the first frequency; after training the command interface while the command interface is operated at the first frequency, reading a vendor specific indicator while the command interface is operated at the first frequency; and, based on the vendor specific indicator, selecting a second operating frequency of the command interface.

Example 2: The method of claim **1**, wherein the memory component is compatible with a graphics double data rate standard (GDDR).

Example 3: The method of claim **1**, wherein the memory component is compatible with a Graphics Double Data Rate 6 (GDDR6) Synchronous Graphics Random Access Memory (SGRAM) specification.

Example 4: The method of claim **1**, wherein the second operating frequency is greater than the first operating frequency.

Example 5: The method of claim **4**, further comprising: training the command interface while the command interface is operated at the second operating frequency.

Example 6: The method of claim **1**, wherein the second operating frequency is equal to the first operating frequency.

Example 7: The method of claim **1**, further comprising: transmitting, to the command interface, a mode register set command to place the memory component in a command interface training mode.

Example 8: A memory controller, comprising: a clock interface to transmit, to a memory component and at a first frequency, a command interface clock; a command interface where the command interface clock determines a first operating frequency of the command interface; and, circuitry configured to train the command interface while the command interface is operated at the first frequency and to, after training the command interface while the command interface is operated at the first frequency, read, while the command interface is operated at the first frequency, a vendor specific indicator from the memory component via

the command interface, and to, based on the vendor specific indicator, select a second operating frequency of the command interface.

Example 9: The memory controller of claim 8, wherein the memory component is compatible with a graphics double data rate standard (GDDR). 5

Example 10: The memory controller of claim 8, wherein the memory component is compatible with a Graphics Double Data Rate 6 (GDDR6) Synchronous Graphics Random Access Memory (SGRAM) specification. 10

Example 11: The memory controller of claim 8, wherein the second operating frequency is greater than the first operating frequency.

Example 12: The memory controller of claim 8, wherein the circuitry is further configured to train the command interface while the command interface is operated at the second operating frequency. 15

Example 13: The memory controller of claim 8, wherein the second operating frequency is equal to the first operating frequency. 20

Example 14: The memory controller of claim 8, wherein the circuitry is further configured to transmit, to the command interface, a mode register set command to place the memory component in a command interface training mode. 25

Example 15: A system, comprising: a memory component to receive commands; and, a memory controller coupled to the memory component via a command interface, the memory controller configured to transmit, to the memory component and at a first frequency, a command interface clock that determines an operating frequency of the command interface, the memory controller further configured to train the command interface while the command interface is operated at the first frequency, the memory controller further configured to, after training the command interface while the command interface is operated at the first frequency, read, while the command interface is operated at the first frequency, a vendor specific indicator from the memory component via the command interface, and the memory controller further configured to, based on the vendor specific indicator, select a second operating frequency of the command interface. 30 35 40

Example 16: The system of claim 15, wherein the second operating frequency is greater than the first operating frequency.

Example 17: The system of claim 15, wherein the memory controller is further configured to train the command interface while the command interface is operated at the second operating frequency. 45

Example 18: The system of claim 15, wherein the second operating frequency is equal to the first operating frequency. 50

Example 19: The system of claim 15, wherein the memory controller is further configured to transmit, to the memory component, a mode register set command to place the memory component in a command interface training mode. 55

Example 20: The system of claim 15, wherein the memory controller is further configured to transmit, to the memory component, a plurality of configuration indicators while the command interface clock is inactive.

The foregoing description of the invention has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed, and other modifications and variations may be possible in light of the above teachings. The embodiment was chosen and described in order to best explain the principles of the invention and its practical application to thereby enable others skilled in the art to best 60 65

utilize the invention in various embodiments and various modifications as are suited to the particular use contemplated. It is intended that the appended claims be construed to include other alternative embodiments of the invention except insofar as limited by the prior art.

What is claimed is:

1. A method, comprising:

providing, at a first frequency, a command interface clock to be used by a command interface of a memory component to determine a first operating frequency of the command interface, wherein the memory component is compatible with at least one of a graphics double data rate standard (GDDR) or a Graphics Double Data Rate 6 (GDDR6) Synchronous Graphics Random Access Memory (SGRAM) specification; 10

training, based on values received by the command interface during the training, the command interface while the command interface is operated at the first frequency; 15

after training the command interface while the command interface is operated at the first frequency, reading a vendor specific indicator from the memory component that was transmitted by the memory component in response to a command sent via the command interface while the command interface is operated at the first frequency; 20

based on the vendor specific indicator, selecting a second operating frequency of the command interface, wherein the second operating frequency is greater than the first operating frequency; and 25

transmitting, to the command interface, a mode register set command to place the memory component in a command interface training mode, wherein the command interface training mode causes the command interface to bridge the values received by the command interface to a direct-quadrature (DQ) interface, to compare patterns received by the memory component to a set of expected values, and to adjust one or more transmit timing values of the command interface based on results derived from the comparison of the patterns received by the memory component to the set of expected values. 30 35 40

2. The method of claim 1, further comprising:

training the command interface while the command interface is operated at the second operating frequency.

3. The method of claim 1, wherein the second operating frequency is equal to the first operating frequency.

4. A memory controller, comprising:

a clock interface to transmit, to a memory component and at a first frequency, a command interface clock; 50

a command interface of the memory component where the command interface clock determines a first operating frequency of the command interface; and, 55

circuitry configured to train, based on values received by the command interface during training, the command interface while the command interface is operated at the first frequency and to, after training the command interface while the command interface is operated at the first frequency, read, while the command interface is operated at the first frequency, a vendor specific indicator from the memory component that was transmitted by the memory component in response to a command sent via the command interface to, based on the vendor specific indicator, select a second operating frequency of the command interface, wherein the memory component is compatible with at least one of a graphics double data rate standard (GDDR) or a 60 65

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Graphics Double Data Rate 6 (GDDR6) Synchronous Graphics Random Access Memory (SGRAM) specification, and to transmit, to the command interface, a mode register set command to place the memory component in a command interface training mode, wherein the command interface training mode causes the command interface to bridge the values received by the command interface to a direct-quadrature (DQ) interface, to compare patterns received by the memory component to a set of expected values, and to adjust one or more transmit timing values of the command interface based on results derived from the comparison of the patterns received by the memory component to the set of expected values.

5. The memory controller of claim 4, wherein the circuitry is further configured to train the command interface while the command interface is operated at the second operating frequency.

6. The memory controller of claim 4, wherein the second operating frequency is equal to the first operating frequency.

7. A system, comprising:

a memory component to receive commands, wherein the memory component is compatible with at least one of a graphics double data rate standard (GDDR) or a Graphics Double Data Rate 6 (GDDR6) Synchronous Graphics Random Access Memory (SGRAM) specification; and,

a memory controller coupled to the memory component via a command interface of the memory component, the memory controller configured to transmit, to the memory component and at a first frequency, a command interface clock that determines an operating frequency of the command interface, the memory controller further configured to train the command interface, based on first values received by the command interface, while the command interface is operated at

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the first frequency, the memory controller further configured to, after training the command interface while the command interface is operated at the first frequency, read, while the command interface is operated at the first frequency, a vendor specific indicator from the memory component that was transmitted by the memory component in response to a command sent via the command interface, and, the memory controller further configured to, based on the vendor specific indicator, select a second operating frequency of the command interface of the memory component, wherein the second operating frequency is greater than the first operating frequency, and the memory controller further configured to transmit, to the command interface, a mode register set command to place the memory component in a command interface training mode, wherein the command interface training mode causes the command interface to bridge the values received by the command interface to a direct-quadrature (DQ) interface, to compare patterns received by the memory component to a set of expected values, and to adjust one or more transmit timing values of the command interface based on results derived from the comparison of the patterns received by the memory component to the set of expected values.

8. The system of claim 7, wherein the memory controller is further configured to train the command interface, based on second values received by the command interface, while the command interface is operated at the second operating frequency.

9. The system of claim 7, wherein the memory controller is further configured to transmit, to the memory component, a plurality of configuration indicators while the command interface clock is inactive.

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